Next Generation Natural Gas Vehicle Program

Vehicle Working Group Workshop
May 2-3, 2000
Chicago, IL

Details of Story Board Recommendations and Votes

NEXT GENERATION
NATURAL GAS VEHICLE PROGRAM

Workshop Goals

- Give participants a clear understanding of the NGNGV Program
- Provide an overview of existing applicable DOE, GRI, SCAQMD, and CEC research
- Obtain input on the technologies and vehicles that should be developed in the program:
  - Vehicle types and markets
  - Natural gas engine technologies
  - Vehicle fuel system and storage technologies
  - Body and chassis technologies
- Gain early interest and support for the program

NGNGV Vehicle Working Group Meeting May 2 and 3, 2000 in Chicago

Over 40 Participants….

- Original Equipment Manufacturers and Vehicle Packagers
  - Crane Carrier Company
  - Cummins Engine Company
  - FAB Industries, LLC
  - Ford Motor Company
  - Freightliner Corporation
  - John Deere Power Systems Group
  - Mack Trucks Inc.
  - Orion Bus Industries
  - PACCAR Technical Center

NGNGV Vehicle Working Group Meeting May 2 and 3, 2000 in Chicago

- Fleet operators
  - United Parcel Service
- Industry/ Trade Associations
  - American Trucking Associations
  - Natural Gas Vehicle Coalition
- Funding Partners
  - California Energy Commission
  - GRI
  - South Coast Air Quality Management District
  - U.S. Department of Energy
- Utilities and Fuel Distributors
  - KeySpan Energy
  - Pacific Gas and Electric Company
  - Southern California Gas Company
- National Laboratories and Research Groups
  - Argonne National Laboratory
  - Brookhaven National Laboratory
  - Idaho National Engineering and Environment Laboratory
  - National Renewable Energy Laboratory
  - Oak Ridge National Laboratory

Workshop Participants (continued)

- Equipment Suppliers
  - CHART-MVE
  - Lincoln Composites
  - Pressed Steel Tank
- Industry Research, Consulting and University
  - Arthur D. Little, Inc
  - ASG Renaissance
  - Battelle
  - BusPlan
  - Institute of Gas Technology
  - Southwest Research Institute
  - The Research Partnership
  - West Virginia University

Input from the Vehicle Working Group

- Participants divided into four groups to provide recommendations on:
  - Vehicle types and markets
  - Natural gas engine technologies
  - Vehicle fuel system and storage technologies
  - Body and chassis technologies
- Groups rotated such that everyone had input to each topic
- Recommendations where then organized and categorized by participants
- All participants voted to identify most critical issues and technologies

Medium-duty CNG
Who are Fleet Customers of Medium-duty CNG
Vehicles that may be Good Potential Customers for
Vehicles from this Program?

- **Mail/Package Delivery (40)**
  - UPS,
    - Atlanta, GA
  - Federal Express
    - Memphis, TN
  - USPS
    - National
    - U.S. Postal Service
    - Merrifield, VA
  - US Express
    - Chattanooga, TN
- **Beverage Delivery(12)**
  - Coca Cola
    - Everywhere
  - Coca Cola Delivery Companies
  - Pepsi Cola Delivery Companies
  - Adwalla juice delivery
- **Shuttles (32)**
  - Major hotel chains
  - Shuttle bus
    - Dial-a-ride
    - Municipal
    - Cal trans
    - El Dorado
  - Tourist "Trolleys"
  - Avis
  - Airport shuttles
  - Commuter buses
  - Airport shuttle fleets
  - Rental/leasing
- **Local Delivery(10)**
  - Staples (delivery vans)
  - Bakery (Entemanns)
  - Home Grocer.com
    - LA Basin
  - Ryder Trucks
    - Lease/rental
- **Undefined(0)**
  - Gas utilities
    - SoCal Gas
    - PG&E
  - Utilities
  - City of Chicago
  - Recreational Vehicles
    - Winnebago, e.g.
      - Insufficient infrastructure in vacation areas
  - Consideration of International markets & trade opportunities
- **Off-ROAD/SPECIALTY (3)**
  - Street & parking lot sweepers in SCAQMD
  - Truck fleet yard tractors
  - Construction
  - Agricultural
- **School BUSES (9)**
  - La USD, La Basin

Heavy-duty LNG
Who are Fleet Customers of Heavy-duty LNG
Vehicles that may be Good Potential Customers for Vehicles from this Program?

- **Long-Haul Mail/Package Transport (13)**
  - USPS National
  - UPS
    - Atlanta, GA
  - UPS
  - RPS
  - Yellow freight
- **Short Haul Grocery/Food/Goods Transport (34)**
  - H.E. Butt Grocery
    - San Antonio TX
  - Miller Brewing
  - Swift Trucking
    - 7-8
  - Safeway (grocery stores)
  - Food Lion Distribution Ctr@
    - Clinton, TN
  - Vons Groceries
    - Los Angeles, CA
  - Continental Bakers
    - Denver, CO
  - Beverage Fleets
    - Soft drinks
    - Beer
    - Water
  - Wal-Mart
  - Shamrock Foods
    - Denver, CO

- **Long Haul (16)**
  - Must emphasize high-mileage line-haul trucks, because these will ultimately have the best economics
    - Various GRI (eg, Zeus) projects show this
    - Apply "gov" funding to overcome infrastructure challenges (i.e., stations) affecting this class
  - Wal-Mart
  - Ryder Trucks
    - Rental/Leasing
  - Private carriers
    - (DelMonte, etc., Roley)
    - (vs. "authorized for hire")
    - where image counts
    - Contact NPTC
- Waste/Trash Haulers (26)
  - Waste Management Palm Desert
  - This customer application is also viable for CNG
  - Browning Ferris
  - Waste Management National
  - Heavy-duty refuse haulers and construction vehicles are strong CNG candidates.

- **Large Shuttle/Transit Buses (7)**
  - Airport shuttles
  - Montgomery County
  - Baltimore
  - Transit bus
- **School Buses (4)**
  - School bus
- **Off-Road (4)**
  - Marine vehicles tugboats/barges
  - Mining vehicles
  - Construction/earth moving
  - Rail-switchers
- **Undefined (1)**
  - Pacific Bell
  - N. California identified (100 fleets) in PG&E market research study

Medium-duty CNG
What Type of Natural Gas Vehicle will be most Needed by the Fleets and Most Useable to Them?

- **Para Transit/Small Bus (35)**
  - 28-32 Passenger School bus
    - Range
  - Para transit
  - Cutaway
    - Super duty
  - Cutaway
    - Class 3 & 4
  - Hotel/rental car Shuttle
    - Integrated chassis
    - Tank placement
    - (luggage storage)
- **Delivery Vehicles (54)**
  - Pickup & delivery
    - Range
    - Performance
    - Noise
  - Delivery truck
    - Package delivery
    - Fueling-time &facility
  - Step vans
    - (e.g. UPS & Fed Ex)
    - 3-6
  - Strip chassis & Cab chassis
    - Fuel economy
- **Other (5)**
  - Street sweeper
    - Elgin
    - Cummins 5.9
  - Small Straight Trucks & tractors
  - General-purpose chassis allowing body builder flexibility
  - A Medium-duty LNG vehicle
    - Range
    - Re-fueling interval

Heavy-duty LNG
What Type of Natural Gas Vehicle will be most Needed by the Fleets and Most Useable to Them?

- **Over-the-Road (29)**
  - Over-the-Road tractor/trailer
    - Range
    - fueling
    - power
    - infrastructure!
  - Tractor-trailer
    - Range
    - Less wt
    - Torque
    - Fuel economy
    - Emissions certified
  - Reliability
  - Durability

- **In-City-Route Trucks (60)**
  - Operations with dedicated routes & terminals (regional haul)
  - Day cab for short haul
  - Para transit
  - Transfer (refuse) truck (long haul)
    - 330-400 HP
    - 1200-1400 ft/lb torque
  - Refuse truck
    - Integrated chassis
    - Weight
  - Refuse hauler
    - Competitive w/diesel
    - 7-8
  - Refuse haulers
    - Performance
    - School bus

- **Off Road (15)**
  - Tugboat
  - Concrete trucks
  - Yard shifters

Medium-duty CNG
What Incentives will these Customers Need to Adopt New Vehicles.
Where are these Incentives Available?

- **Life Cycle Cost (38)**
  - Fast cost payback
  - Lifecycle cost
    - Validated, standardized model for "life cycle cost"
  - Fuel economy
  - Cost!
    - Fuel, maintenance initial cost, subsides
  - Initial cost same as equivalent diesel
  - Financial incentive to offset incremental purchase cost +
    - (Maryland DOT)
  - Hassle free
  - Low operating cost to overcome fuel storage and fill costs
  - Cost differential rebate
    - Illinois
    - 3-6
  - Long term fuel $ commitment from gas company
  - Operating cost incentive
  - Long term need - BIG fuel price differential
  - Vehicle & engine Differential Cost
  - Carol Moyer – CA
  - MSRC – LA basin
- **Tax Credits (31)**
  - Jeffords/Hatch Bill
    - .25/gal tax credit on fuel
  - Tax credit on fuel used
  - Eliminate of state excise tax on NG
  - Waiver of registration fees & State sales tax
  - Reduce local taxes
  - State policy/incentive
    - 3-6
  - Individual SIP incentives
    - 3-6
  - Individual SIP incentives
- **Customer Satisfaction (6)**
  - Noise reduction
  - Lower noise than diesel
    - At least 10 dba less
  - Drivers & neighbors
  - Indemnification for lost service/clients
  - HOV opportunity
  - Image!
  - Real world range claims
  - Extended fuel system warranty
  - Expanded warranty
  - Access to service/parts guaranteed over life of vehicle
  - Insurance subsidy
- **Emission Credits (15)**
  - Emission Credits
  - Emission reduction incentives
  - Colorado incentive program
  - Mobile emission credits
  - NOx credits
- **Mandates (2)**
  - Regulatory relief
  - Fleet rule
  - Epact credit
  - Punishment avoidance (lawsuits)
  - Requirements to use NGVS (AFVs) (re: SCAQMD)
- **Infrastructure (20)**
  - Friendly refueling infrastructure
  - Infrastructure
  - Infrastructure cofunding
    - CA Energy Comission
  - Impoved Safety during Fulling & Operation

Heavy-duty LNG
What Incentives will these Customers Need to Adopt New Vehicles?
Where are these Incentives Available?

- **Tax/State Credits Incentive Programs (32)**
  - Lower road taxes
  - Federal Jeffords/Hatch bill
    - 0.25/gge tax credit
    - Tax credit on increm. Price
  - 7-8 epact credits
    - (Energy policy act)
  - Regulatory relief
  - Fleet rules
  - Epact credit
  - 3-6 Epact credits
  - Vehicle & engine differential tax credits
    - Carl Moyer – CA
    - MSRC – LA Basin
  - Waiver of registration fee/state sales tax
  - Fuel savings
  - Tax credits
  - Lower fuel tax
  - Tax credit on incremental vehicle cost
    - Simpler than applying for Moyer $
  - Elimination of State Excise Tax on LNG
  - Continue & expand Carl Moyer program in CA
    - Try to extend to other states
    - Carl Moyer program was adopted after trying to make mobile emissions credits work)
  - Requirements to use NGVs/AFVs re: SCAQMD
  - Guaranteed Fuel Availability
- **Clean Air Emissions Credit (19)**
  - Emissions/State Pressure
  - Emissions credits
  - NOx credits
  - Mobile emission credits
- **Fuel Costs (30)**
  - 7-8 long term fuel $ commitment from Gas Co.
  - Cost
    - Fuel, maintenance, initial cost, subsidies
  - Lower fuel cost
  - Incremental cost of vehicle
  - Emissions based incentives
    - Maryland/WashCOG Vehicle replacement program
  - Tax credit on fuel used
- **Customer Satisfaction (21)**
  - Image
  - Image – (attracting drivers)
  - Guaranteed cost savings (as in Power Gen installations)
  - Lower noise level from engine at least 10 dBA
    - (Driver incentive/late night delivery)
  - An LNG training program
  - Provide LNG fueling stations for class-8 line-haul trucks
  - Infrastructure
  - Swat team assistance to help customer identify problem cause (vehicle vs station)
  - Life cycle cost
  - Certified as ILEV for access to HOV lanes
  - Does it take more incentive for a class 7-8 LNG customer than class 3-6 CNG?

Medium-duty CNG and Heavy-duty LNG
What Performance Specifications will these Customers Need to Adopt New Vehicles?

- **Performance**
  - Diesel-like torque rise (gradeability)
  - Consider poor part load efficiency (throttled) before choosing vocation
  - Driveability
    - Easy-to drive
    - Good feel/response
  - Easy to use
    - Idiot proof
  - Driveability
    - Easy to drive
    - Good feel/response
  - Improved fuel economy
  - Consider poor part load efficiency of SING in choosing vehicle

- **Cost (50)**
  - Improved fuel economy
  - Equivalent fuel use at idle
  - Cost of ownership
  - Customers are not favorable of dual fuel technology
    - Cost of maintenance
    - Drivers complain
    - Very difficult to sell
  - Durability
  - Heavy-duty demo should emphasize:
    - Fuel efficiency
    - Driving range
    - Over-the-road usage
    - Diesel-based engine

- **Maintenance (17)**
  - Low maintenance costs
  - Safety & cost and cost & safety
  - Medium-duty demo should emphasize:
    - Low cost system
    - Use gasoline-based engine (cost/wgt saving)
    - Low emissions (tailpipe & evap)
    - Low speed usage (city)
    - "Smaller" engine
  - East of fueling
  - Reliability

- **Other (1)**
  - Operations in environmentally sensitive areas

What Engine Performance Features will be Important to Customers of Natural Gas Vehicles in 2004?

- **Durability (5)**
  - Diesel-like Durability
  - Robustness
    - Altitude
    - Gas quality
    - Humidity
- **Maintenance (15)**
  - Better maintainability
  - Low maintenance Costs
  - ≥ maintenance (e.g. spark plug changes)
  - 50,000 mile Spark plugs
  - No injector problems
- **Oil Compatibility (0)**
  - Extended oil change intervals
- **Smart Diagnostics *on-board diagnostics (2)**
- **Reliability** (1)
- **Increased Range (3)**
  - High flow, low-pressure injectors for better range
- **Fuel Economy (30)**
  - Fuel economy equivalent to diesels
    - Duty cycle dependant
  - Fuel consumption similar to diesel
  - Diesel-like Fuel economy
  - equivalent idle and part load fuel economy
  - Low cost and high mileage performance
  - Near 50% thermal efficient engine

- **Lower Cost (31)**
  - Lower operating cost than diesel
  - Equal fuel economy
  - Longer service intervals
  - Lower maintenance cost
  - Less than or equal to original cost
  - Low cost engine-gasoline-based (class 3&4)
  - Lower 1st cost
- **Lower Emissions (11)**
  - NOx < 1.0 g/hp hr
  - Peak efficiency > 45%
  - Low PM emissions
    - Approaching 0.00
  - Low emissions
    - 0.5 gm NOx
    - 0.01gm PM
  - Low leakage injectors to meet tier II evaporative requirements
- **Engine Packaging (1)**
  - Less heat in engine compartment
  - Integrate engine electronics with fuel control
- **Fuel Quality (1)**
  - Ability to adapt to off-specification (low quality) fuel
  - Utilize a wide range of fuel composition
  - Capability to operate on range of fuels (engine)
    - ≥ 88% CH4
    - ≤ 8% C2 +

- **Other (2)**
  - Accommodate “non-lubed” fuel L/CNG
  - Injectors that do not require oil in gas
  - Injectors that are tolerant of oil in gas
  - Injector systems reliability & durability
- **Driveability & Performance (15)**
  - Driveability,
    - power, torque, low end torque
  - “Matched” engine-transmission-drive train
  - Diesel-equivalent driveability, torque, & power
  - “Diesel-like” gradeability (i.e. torque)
  - Torque Rise
  - Idle & full load performance
  - Performance equal to or better than diesel
  - Power density and torque acceptable for vehicle application
  - Easy cold weather starts
  - Is throttle a good enough retarder (as Jacobs brake substitute for Class 8 line haul)
  - Engine performance goals must be relatively success-oriented. Goals that re too conservative will produce a boring program that will not receive continued funding.

What Engine Technologies should be Incorporated into Leading Edge Vehicles in 2004?
Combustion Types

- **DING (21)**
  - Advanced DI NG
  - High pressure direct injection
  - Direct injection capability for natural gas
  - Demonstrated @ steady state
  - High pressure cryogenic pump
  - Cryogenic pump development
  - Fuel injector pump development
  - Late-cycle direct injection..
    - o Dedicated NG if suitable low Cetane tech. Emerges;
    - o Dual-fuel (pilot) if not
    - o Barriers are well-resources
    - o R&D underway
  - Non-diesel pilot direct injection, e.g., w/glowplugs
- **HCCI (0)**
  - Homogeneous charge compression ignition (HCCI)
  - Limited steady state tests on NG – production on diesel
  - High load/transients/fuel properties
  - Variable load combustion development
- **SING (18)**
  - Ultra-lean burn SI
  - Advanced SING
- **Rich burn with EGR (17)**
  - Stoic NG combustion for low emissions with after treatment
  - Stationary NG engines lower durability
  - Higher temperatures
  - Engine & after treatment development
  - Consider spark ignited stoichiometric w/3 way cat for ultra low emissions (but poorer efficiency)
  - Stoichiometric w/high efficiency (very low emissions)
  - Production/efficiency low
  - Fuel economy/EGR tolerance
  - EGR tolerant combustion
- **Micro-pilot Ignition (4)**
  - Laboratory Preproduction
  - Injector/combustion-Part Load
  - Transient Engine Development
- **Direct Injection Stratefied Charge (0)**
  - Production for Gasoline
  - Injection life/Disc specific combustion chamber
  - Injector DAD Combustion system development
- **Prechamber ignition (0)**

What Engine Technologies should be Incorporated into Leading Edge Vehicles in 2004?
Combustion Strategy

- **High BMEP capable (1)**
  - Diesel-like
  - Lean combustor
- Miller-cycle engine enhancement
- Variable CR
- Knock tolerant combustion (SING)
  - Production (gasoline)
  - Commitment for gas products (i.e. customers)
  - NG specific cylinder heads
- Regenerative intake air cooling (LNG)

What Engine Technologies should be Incorporated into Leading Edge NG Vehicles in 2004?
Other Technologies

- **Full electronic controls (6)**
  - More accurate fuel metering
- **Fuel or A/F ratio sensors for engine control (2)**
- **Knock sensing (0)**
- **Advanced spark/ignition systems (0)**
  - Skip-fire
  - EGR sensor
    - o May help control engine performance
    - o EGR
    - o Gasoline & diesel
    - o Engine combustion system
  - EGR not required with after treatment
    - o Lean NOx
  - EGR
    - o Limited steady state data
    - o Controls
    - o Develop control strategies/hardware

- **Minimum change to the diesel platform (0)**
  - EGR
  - After treatment
- **Advanced diagnostics (3)**
- **Fuel composition detection/adjustment (7)**
  - Low cost
  - Btu
  - Methane
  - Ethane
  - Propane
  - Inerts
- **Hotel load management w/engine off (3)**
  - Anti-idling using aux. Power supply for heating/cooling (for long haul)
  - Auto stop/start to reduce idling
  - Don't forget cooling fan loads in considering vehicle (not engine efficiency)
  - Reduce cold-start emissions

- **Advnced turbo charger (0)**
  - Durable turbo charges
  - Turbo machinery optimum for gas engines
- **OBD (0)**
- **Speed density 3-way catalyst fuel systems (5)**
- **Durability/Reliability**
  - Improve oil control technologies (6)
  - Develop economic durable spark plugs for N.G. engines (1)
- **Not Yet Defined**
  - Low NCET pressure required to maximize utilization of fuel storage (6)
  - LNG high pressure vs low pressure issues (3)
  - CNG – lower inlet valve pressure to utilize all fuel in tank or pressure boost pump

What are Current Engine Development Projects that the NGNGV Program Should "Piggyback" on?

- **Advance Reciprocating Engine Systems (12)**
  - Stationary
- **HCCI combustor (3)**
- **SI & CI**
  - Advanced controls diagnostics (1)
  - 0.5 gm Nox/0.01 pm ACMD proposal (9)
    - Cindy Sullivan
  - Larger, lower cost CNG injectors, with lower sensitivity to fuel quality (lack of lubricity) (20)
    - IMPCO developing a candidate
  - DING (4)
  - Skip-fire

- **Spark Ignited**
  - Enhanced efficiency (32)
    - High efficiency HD NG engine development program
  - Individual engine development (4)
    - DDC (Deere) – Cummins (Mack)
    - 2.5 → 2.0 → 1.5
  - SULEV emission level engines are in production for class 3 (1)
    - Ford 5.4L V8
  - Baytech ULEV (4)
    - GM 5.4 & 6.0L engine

- **Compression Ignition Dual Fuel, Include Micropilot**
  - Westport pilot injection (11)
    - HPD1 development program, which is primarily company (not government funded)
  - Micro-pilot ignition (4)
    - Clean air partners/BKM
  - Electronic Fuels Controls, Inc.
    - Navistar dual fuel engine development

What After Treatment Devices Should be Investigated for NGNGV(s)?

Other Controls

- **HDNG after treatment (0)**
  - R&D should be integrated with (not separate from) NG engine R&D … and be as required to meet emissions goals
- **Catalyst protection from contaminants (sulfur) (28)**
  - Research underway
  - Time +
  - Testing on NG (as opposed to diesel) engines
- **Hythane (1)**
  - Adding H2 to NG extends lean limit to reduce NOx

- **Lean NOx Catalyst (32)**
  - Lean NOx adsorber
  - After treatment for lean combustion
  - Low NOx CAT
  - Lean burn engine with lean NOx CAT
    - Lean burn engine with lean NOx CAT not available – heat engines available
    - Successful catalyst
    - Catalyst development
  - Lean NOx catalyst for NG
    - Current work focus on diesel
    - Emphasis on diesel business
    - Access effectiveness of experimental lean NOx diesel catalysts/identify others

- **Total HC Reduction (28)**
  - Consider hydrocarbon emissions reduction too – in 4 yrs CH4 will be watched as a greenhouse gas
  - CH4 oxidizer
- **Oxidation Catalyst(9)**
  - Durable oxidation catalyst to achieve 0.01 pm over engine's useful life
    - Has not been a target in the past
  - 3-way catalyst
    - Gasoline & NG stoie eng cats.
    - High temps of combustion
    - Engine & CAT durability
  - Aldehyde control
- **SCR (SRC) (3)**
  - Selective reduction CAT for 0.5 g/NOx
  - Diesel teen- used in EEC
  - Cost & additional fluid storage
  - Development for lean NG engine
  - Urea? – It would work!

Medium-duty CNG
What Fuel System & Storage Features will be Important
To CNG Vehicles in 2004?

- **Safety**
  - On-board monitoring of CNG cylinder integrity (23)
    - "active" system not needing periodic monitoring.
    - On-board inspection
    - In-use, real time inspection
    - On board testing?
    - Smart tank technologies:
    - # of fill cycles
    - surface damage detection
  - NDE of used tanks (1)
  - Leak Detection (0)
  - Accessibility for inspection/removal (0)
  - On-board protection against over pressure(0)
  - Fail-safe fuel Shutoff at tank Triggered under accident condition
    - Already in production

- **Durability**
  - Longevity (5)
    - longer life of components & features
    - Durability/reliability
  - Fuel tank robustness (3)
    - not affected by environment, impact damage, fuel composition etc.
    - Integrated protection against impact damage to containers
    - Standard validation test

- **Smart Fueling**
  - Temperature compensated fueling system to get full fill (16)
    - Temperature-compensated full fill
    - Reduced-temperature quick fill
    - System sized to accommodate a fast fill of no more than 5 minutes duration
      - Too long
  - Accurate metering (11)
    - Accurate quality in the tank
    - Fuel station maintenance and cost
    - Vehicle time to fill requirement
    - Smart filling – vehicle and station communicate fill under all conditions
    - Combine with fuel composition sensoring in station
    - Maximize storage volume for range
  - Filling operation simplify & speed connections @ fill stations (3)
    - "User Friendly" fueling.

Medium-duty CNG
What Fuel System & Storage Features will be Important
To CNG Vehicles in 2004? (continued)

- **PRD/Component Improvement**
  - Manifold PRD vent system with ability to drain water(2)
    - Simplified standard guidelines for PRD vent systems NFPA 52
    - Eliminate PRD vent systems.
  - Zero failure PRD (3)
    - More reliable/longer life PRDs
  - Durable high pressure regulators (1)

- **New Tank Concepts**
  - Have a diesel saddle tank look (0)
  - Conformal tank designs for small vehicles (0)
    - LNG will dominate truck market
  - Torroidal tank for improved packaging in "flat" spaces (0)
  - Low pressure (500 psi) storage technology (6)
    - Adsorbed natural gas (ANG) with comparable storage density to CNG @ 3600 psi
    - Cost savings 500 psi versus 3600 psi
    - Adsorptive gas storage

- **Lower Weight (3)**
  - Light weight
    - Low-weight Fuel storage Module
    - ~ .15 lb/cc ft
    - minimize weight
    - < .1 lb/SCF
- **Higher Capacity**
  - Improved Volumetric Efficiency (5)
    - Max. capacity
    - Compact Fuel Storage (Packaging)
  - Consider larger & fewer tanks for improved cost and weight efficiency (4)
    - 20+ "diameter ≥ 80" long
  - Operating pressures higher? (0)

- **Evaporative Emissions (2)**
  - "Zero"-evaporative emissions
    - Vent-managed regs
    - No-leak fittings
    - No container permeability
    - Satisfy carb/EPA evap. Std.
  - Low permeability flexible fuel lines to meet Tier II evaporative emissions
  - Minimize leak points throughout storage system
- **Defueling**
  - Easy/safe/emissions friendly
  - Defueling
  - Defueling system
  - Develop workable and safe system to defuel cylinders without venting to atmosphere.

Medium-duty CNG
What Fuel System & Storage Features will be Important
To CNG Vehicles in 2004? (continued)

- **Lower Cost**
  - Lower-cost containers (21)
    - significant portion of system cost
    - material cost ~50% total, so less (thinner wall) needed
    - Low cost tanks <$.90/SCF
    - Low cost
    - Cost
    - Develop lighter weight and more economical Type 3 cylinders.
    - Reduced cost tanks
      - ≈ $.50/SCF
  - Lower cost brackets (0)
    - Mounting Systems
  - Low cost high pressure Ancillaries (1)
    - Lines
    - Terminal
    - Valves
    - Sensors
    - PRDs
    - Simple
    - less fittings
  - Modular design (4)
    - "Pop in/Pop out" for maintenance/replacement
  - Cost Reduction on PRD Systems (0)
    - Low Cost PRDs

- **Misc**
  - Fuel gauge that reads tank/cylinders correctly (0)
    - Still looking for one
  - Standardized components across platforms/OEM's(0)

- **Integration**
  - Integrated vehicle/fuel system/storage design (1)
    - Fuel system/storage design
  - Integrated storage modules (3)
    - container – brackets
    - fuel lines – shields
    - valves – sensors
    - PRDs
    - Tank – mounted
    - Valve protection
  - Low pressure fuel lines (1)
    - i.e. – regular at tank to operating pressure
    - In tank Solenoid & Regulator
  - Low cost integrated heat exchanger for 3600 psi systems

Heavy-duty LNG
What Fuel System & Storage Features will be Important to LNG Vehicles in 2004?

- **Tank integrity (4)**
  - Vehicle fuel tank to outlast the engine with only routine maintenance
  - Vacuum/fitting integrity
  - Tolerance to overroad vibrations
    - Std needed
- **Low-cost tanks (14)**
  - Lower cost tanks
  - Lower cost
  - Lower cost tanks
  - Standard size tanks
- **On-board accurate fuel gauge (11)**
  - System to gauge fuel level under varying conditions
  - Fuel quantity
  - Accurate fuel gauge
  - On-board, linear at low tank level
- **Tank defueling (7)**
  - Tank defueling capability
  - Defueling system for LNG vehicles for emission, safety and fuel recovery T. Barker
  - Easy/safe/emission friendly defueling

- **System Integration (14)**
  - Ability to fuel multi-tank systems completely & quickly
  - "Systems" designed fuel system
    - Pipe diameters
    - Correct size heat exchangers
    - Multi tank manifold
  - Compact fuel storage (packaging) energy density & volumetric efficiency
  - Ability to store fuel on vehicle at low pressure & high density
  - Ability to manage fuel tank pressure
  - Maintain low storage pressure while providing "high" fuel rail pressure
  - Avoid pressure building in tank and venting of CH4
  - Vehicles designed to accept cylindrical tanks
  - Low cost more efficient heat exchanger
  -

- **Safety-CH4 Detection (3)**
  - Odorized LNG
- **High Pressure Engine Fuel Pump (4)**
  - Reliable high pressure fuel pump for vehicle
  - Capability of providing 3000+ psi NG to support late-cycle DI engine requirements
- **LP Storage - Maximize Energy Density (18)**
  - Lower LNG pressure (colder)
  - Need low pressure fuel metering system as enabler
    - Yes! Nice one – integrate storage + fuel system (engine concepts)
  - Ability to relieve LNG station of fuel "preconditioning" requirement
  - Low pressure (~20 psi) storage pressure
  - Lower pressure – maximizes

Heavy-duty LNG
What Fuel System & Storage Features will be Important to LNG Vehicles in 2004? (continued)

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● **Venting Management (15)** • Tolerant of long times between refueling • Boil-off management • Low permeation fuel lines, fittings and diaphragms for Tier II evap emission requirement o Will evap be methane or just NMOG? • Controlling LNG boil off • Minimize evaporative emissions • Vent gas neutralization • Reduce losses during refueling and non-use • More effective, light weight insulation • Low weathering loss for improved range, and fuel composition (to engine) • Zero leak to atmosphere • LNG evaporative losses • Adsorptive traps	● **Standardize Receptacle – User-Friendly (21)** • User Friendly o No protective clothing o No leaks /spills o Easy connection o Light-weight/easy to handle • Compatible fuel nozzle receptacle • Automated fueling • Anti-splash provisions for receiving safely • User friendly dispense o (so you don't have to hit the nozzle w/a hammer to get the ice off.) • Complete treatment of fueling safety issues • User friendly fuel system • No self-serve fueling on line • 1 vs 2 hose systems • Safety during filling operation	-

Medium-duty CNG
What are Current Fuel System & Storage Development
Projects that the NGNGV Program Should "Piggyback" on?

- **Cost Reduction (35)**
  - Reduced-cost CNG storage, such as high-strength Steel
    - PST
    - Faber
    - Norris
  - GRI/DOE improved Type IV development study
    - GRI
  - Lower-cost type 4 container
    - Lincoln composites
  - Low cost mfg process for all type high pressure tanks
    - All tank manufacturers
  - Low cost Type 3 container
    - PST
  - Large diameter tanks
    - 20"
    - PST
  - High Strength Steel/Aluminum Container Development, GRI
  - Multi shield, All composite tanks, Calstart
- **System Safety (22)**
  - Acousto ultrasonics – for on-board damage sensing, Battelle
  - Impact damage sensing coating, Battelle
  - Leak prevention & detection, SAE
- **Fuel Control & Piping (26 ¾)**
  - Improve system component selection
    - Fittings
    - Valves
    - Relief devices
  - Low-cost, impact resistant fuel line terminals.
  - Low-cost Combination PRDs
  - Integrated pressure regulator and tank valve for reduced cost, simplification and improved safety/emissions. IMPCO, Veritek and GFI have projects.
  - Reliable pressure regulators
  - Single & dual stage
  - Robost, high flow, Positionable tank valves
  - GRI Systems Integration, Recommended guidelines for designing & installing fuel systems, Battelle
  - Improve multitank manifolding, FAB
  - Low cost, compact automatic tank valve (solenoid).
- **Volumetric Efficiency New Concepts**
  - Thiokol conformable tanks , Thiokol (2)
    - APL/JHU ISS (Integrated Storage Systems) Project,
  - Low pressure (adsorbed) fuel storage, ORNL (6)
    - DOE OTT heavy vehicle systems
    - ORNL adsorbed natural gas technology (500 psi)

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Heavy-duty LNG
What are Current Fuel System & Storage Development
Projects that the NGNGV Program Should "Piggyback" on?

- **Liquefier Projects**
  - Small scale liquefaction (6)
    - Cryofuels systems
    - Small scale liquefier IGT
    - Low pressure
  - Small scale liquefaction (10)
    - Pacific Gas & Electric
    - Small scale liquefaction
    - Southern California Gas Co
    - Pressure let down
  - Small scale liquifier (0)
    - Thermo-acoustic
    - Cryenco/Chart
- **On-Board Pump and Pressure Build Projects**
  - Ineel's 2001 development of an advanced economizer that maintains low tank pressure while providing "high" pressure to fuel rail (12)
    - Pressure building device for fuel tanks
    - IWG-Ineel
  - LNG pump technology (25)
    - Westport
      - Brookhaven
    - High-pressure Liquid + vapor Pump Dev.
      - [DOE-BNL program]
    - LNG vaporizer – driven LNG pump technology to enable:
    - Storing low-pressure high – density LNG in tank
    - Providing NG to engine at any needed pressure (100-3000+ psi)
    - Managing fuel tank vapor pressure
    - DOE – BNL program underway
- **Low cost stations projects (21)**
  - Low cost fuel station, INEEL
  - Low cost fuel station, Chart
- **Tank Development Projects (10)**
  - Non-weathering tank, Chart
  - Low pressure LNG storage Tank, BNL project
- **SAE/IWG Projects**
  - Odorized LNG (5)
    - IWG-SAE fuel composition
  - Standardized receptacle for fueling (2)
    - IWG & SAE –
  - Weights & measures certified metering (10)
    - SAE LNG task force, Chart
  - NGV-IWG LNG task force for station/Vehicle compatibility (0)
  - Precise fuel metering (0)
    - Weights & measures approved meter for retail sales

Medium-duty CNG
What Vehicle Body Developments that are Ready Now,
or will be Ready by 2004 should be Incorporated
Into the Medium-duty Prototype Vehicle?

- **Design**
  - Our vehicle should look just like "conventional" vehicle EXCEPT for NG fuel system (12)
  - Consider/Assess All existing designs (5)
    - FCC bluebird
    - Use a recently introduced cab suitable for the selected application (recent as a 2004)
  - Provision for tank location (CNG) which do not require pro vent lines (medium CNG) (6)
  - Design body to accommodate conformal tanks and large after treatment devices (but allow for tank inspection)(23)
    - Design to accommodate large DIA tanks for improved cost/wt. Eff.
  - Medium-duty paratransit bus (16)
    - Low floor
    - Roof mounted CNG tanks
    - Low entry for driver
    - Body/Chassis Design
      - Designed exclusively for CNG vehicle, not diesel-based with "bolt on" CNG system. For example – new approach for placement of storage system to give better maintenance access. Make unique needs of CNG an integral part of body/chassis design.
- **Materials**
  - Use lightweight materials (4)
  - Light weight tanks (1)
  - Extensive use of light weight composites and aluminum (1)
- **Safety**
  - Tank – safe design accessible for safety inspector (3)
  - Design for crash worthiness (0)
  - Use structural integrity of storage tank to minimize/reduce weight of chassis/body (9)
    - Comment – frames are designed to flex.
- **Features/Other**
  - Ask the customer! (13)
  - Cab temperature management – glazing; insulation; PV-assisted ac/heater (3)
  - Incorporated aerodynamic features for efficiency and to emphasize forward thinking design (1)
  - Instrumentation (1)
  - Ergonomics (0)

Medium-duty CNG
What Vehicle Chassis Developments that are now Ready or will be Ready by 2004 should be Incorporated into the Medium-duty Prototype Vehicle? (continued)

- **Chassis Technology**
  - Current state of development
  - Types of vehicles for which the technology is applicable
- **Intelligent Vehicle Systems**
  - CAN Buss (2)
    - Communications for chassis, engine, trans
  - Vehicle self diagnostics (4)
    - Smart vehicle that communicates problems
- **Cost**
    - OE
    - Maintenance
  - Class 3-6 mid-range chassis cost (2)
  - Maintenance cost cannot exceed diesel maintenance cost (9)
- **Stay where you are**
  - Our vehicle should look just like "conventional" vehicle except for NG fuel system (19)

- **Cats & Dogs**
  - Possible integrated body & chassis for Class 3&4 (1)
  - Increased weight carrying capacity (3)
  - Class 3-6
  - Fuel Fill time 5 min or less (11)
    - Equal fuel capacity to present diesel
  - Consider "lessons learned" from past other NG product development efforts i.e. USPS 2-ton truck project (2)
  - Provide an integrated vehicle test prior to placing prototype in service (1)
    - "Work the bugs out"
  - Run flat tires (0)
    - more space for CNG tank
  - Cut away (12)
    - Cut away chassis for shuttle vehicle
  - Continuously variable transmissions (CVT) (11)
    - Can be used to make up for fuel economy penalty with NG allows engine to operate under limited range

- **Design Vehicle for NG**
  - Incorporate container "strength" into chassis design (0)
    - Concerns about tank integrity
  - Chassis can be different to accommodate fuel storage without affecting body appearance (0)
  - Vehicle design able to accommodate low pressure adsorption for storage (2)
    - Assume this technology won't be ready by 2004.
  - Utilize voids in body to "fit" fuel storage (14)
  - Provide large, unobstructed spaces for mounting the fewest large tanks (17)
- **Frames**
  - Use tank structure to transfer crash impact loads to reduce shield lost weight (6)
  - Use aluminum in frame components to save weights (3)
    - Cost penalty
  - Lightweight frames (1)
    - Low pressure storage @500 psi integrated into Chasis/frame
  - Hydroform (2)
    - Frame components for light weight & strength

Heavy-duty LNG
What Vehicle Body Developments that are Ready Now, or Will be Ready by 2004 should be Incorporated into the Heavy-duty Prototype Vehicles?

- **Body Technology**
  - Current state of development
  - Types of vehicles for which the technology is applicable
- **Design**
  - Use a recently introduced cab suitable for the selected application (recent as of 2004) (2)
  - Build refuse trucks (5)
  - Better vent design to avoid water intrusion (0)
  - Watch 21st Century truck program (1)
  - Our vehicle should look just like "conventional" vehicle except for NG fuel system (3)

- **Fuel System**
  - Body & chassis features that accommodate any LNG tank and fuel system standards promulgated by SAE or other ora l. (e.g : tank shields or shrouds) (16)
  - Design to accommodate fuel tank(s) (not an after thought) (32)
  - Chassis OEM integrate fuel system (0)
  - Relocate battery box to allow for longer LNG tank to replace existing diesel tank (0)
  - Greater fuel storage quantities(4)
  - Design for FMVSS crash testing worthiness (0)
    - o Comment – consider drop-test of tank, like diesel tank
  - On-board methane detection system that has low current draw and is reliable (4)

- **Features**
  - Need to consider underhood cooling carefully if using novel aerodynamic design (1)
  - Anti-idling (19)
    - o Using AUX power for cab power, heating & cooling to reduce vehicle engine (class 7/8, long haul)
  - GPS, Global positioning (0)
  - CAN communications for chassis, body, trans engine (1)

Heavy-duty LNG
What Vehicle Chassis Developments that are Ready Now, or will be by 2004, should be Incorporated into the Heavy-duty Prototype Vehicles?

- **Stay where you are**
  - Our vehicle should look just like "conventional" vehicle except for NG fuel system (14)
- **Motherhood**
  - Involve the customer (always) (6)
  - Chassis OEM be willing to build a truck w/NG engine (15)
  - "Piggyback" 21st Century truck (2)
  - Revised max weight laws so that any extra weight of NG storage & engine components do not penalize truckers' payload capacity(3)
  - Incorporate as many existing and advanced tech. W/o investing program R&D funds on non-NS advancements (5)
  - Provide an integrated vehicle test prior to placing prototype in services (1)
    - o "Work the bugs out"

Other Ideas and Issues for Body and Chassis Technologies

- **Tanks**
  - Advanced LNG tank protection for crash (11)
  - Allow for larger diameter LNG tanks to replace existing diesel (4)
  - Incorporate fuel tanks within frame for crash protection (3)
  - Lower cost storage options (3)

- **Tires and Brakes**
  - Improved brakes (0)
  - Low rolling resistance tires (0)
  - Super single tires (0)
  - Design chassis to accept retarders – or is throttled engine braking enough? (1)

- **Other**
  - Improved aerodynamics, CL.7/8 (0)
  - Natural gas, auxiliary power, unit (no engine idle) (9)
  - Advanced cooling system components (13)
    - Radiator
    - Electric water pumps
    - Nano-fluids?
  - Greater cooling system capacity to accommodate advanced emissions controls (2)
    - Such as 3-way catalysts & EGR
  - Drive line optimization better integration with a NG engine torque curve (12)

Parking Lot		

• **Fuel quality issues**
  • did not see it covered anywhere (see SAE LNG task force)
• **Heavy hybid**
• **Vehicle demo for potential customers**
  • No blind faith
• **Safety**
  • No leaks
  • Ease of detection if leaks do occur
  • Reputation of safety
  • User friendly fueling?
	• **Need basic research to continue or NG will get behind diesel and others even further!**
	• **Warranty - 100,000 – 200,000 miles on all components, Medium-duty**
	  • Higher on Heavy-duty
	• **Integrated chassis/fuel system warranty**
	• **Do market research?**
	• **Rental/Leasing**
	  • Can't trust the public yet!
	  • Must be hassle free to get rentals by 2004
	• **Get customers onboard-visit**
		• **What is commercial viability?**
		  • # of vehicles
		  • Define criteria
		• **Market studies**
		  • GRI
		  • PG&E